

LEIDENDEKER

An Investigation of the
Effect of Keyways on the
Torsional Strength of Shafts

Mechanical Engineering

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AN INVESTIGATION OF THE EFFECT OF KEYWAYS
ON THE TORSIONAL STRENGTH OF SHAFTS

BY

Frank Earl Leidendeker

• THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE
IN MECHANICAL ENGINEERING

IN THE
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OF THE
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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

FRANK EARL LEIDENDEKER

ENTITLED AN INVESTIGATION OF THE EFFECT OF KEYWAYS ON THE

TORSIONAL STRENGTH OF SHAFTS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Mechanical Engineering

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INTRODUCTION.

Much has been written on the subject of keys with regard to their form, size and the manner of fitting them; and many tests have been made to determine the holding power and strength of the different forms. By means of these tests certain forms and sizes of keys have been adopted as standard, and information about them may easily be obtained from the catalogues which the manufacturers issue and from such publications as Kent's Mechanical Engineer's Pocket-Book. Very little has been done toward determining the relation between the size of keyway and the strength of the shaft, as it is seldom that the shaft fails before the key gives way. However, it is obvious that if material is removed from the shaft, the strength of the shaft will be decreased, and where a carefully computed design is being made, the diameter of the piece should be increased to allow for the material removed.

OBJECT.

The object of this investigation is to determine the effect of the different forms and sizes of keyways on the torsional strength of shafts, both cold rolled and turned. The effect of the special keyway used for the Woodruff key will also be found.

MODERN PRACTICE.

There are two methods used for fastening pulleys to shafts, by set-screws and by keys. The set screw is convenient

where the power to be transmitted is small or where the pulleys are put up only temporarily, but in most cases keys are found to give the best satisfaction for attaching pulleys or wheels to shafts. In most cases where keys are used, they are put in only for the purpose of keeping the pulley from turning on the shaft, and they drive by shearing stress alone. In other cases the keys are used to prevent the pulley from sliding along the shaft, as well as for transmitting power, and they are machined so that they fit on all sides or as commonly said "bear all over". This form is tapered and must be driven in tightly, thus often causing a strain in the hub of the pulley. On account of the expense of fitting the tapered keys they are seldom used and the square keys that bear tightly on two sides but have clearance on the top and bottom are generally used instead. Where the shafts are made for sliding bearings as in the case of drilling machine spindles, the depth of the keyway is generally made greater, and when there is a heavy stress on it two keys are sometimes placed at right angles to each other in the shaft.

Different firms use different formulae for the sizes of keys and keyways used in their work, these generally having been determined by practice. In the Michigan saw mills the width is made one-fourth the diameter of the shaft and the depth one-eighth of the diameter; the dimensions being taken to the nearest sixteenth of an inch. E. G. Parkhurst in the Trans. A. S. M. E., vol. 13 gives the following dimensions for flat taper keyways: width, $\frac{1}{8} D$ and depth, $\frac{1}{6} D$, where D is the diameter of the shaft. Taper, $\frac{1}{8}$ inch per foot. For the keyways

used in the tests the width was about one fifth of the diameter of the shaft and the depth was one-half of the width. The dimensions were taken from the table in Kent, page 977.

METHODS OF TESTING.

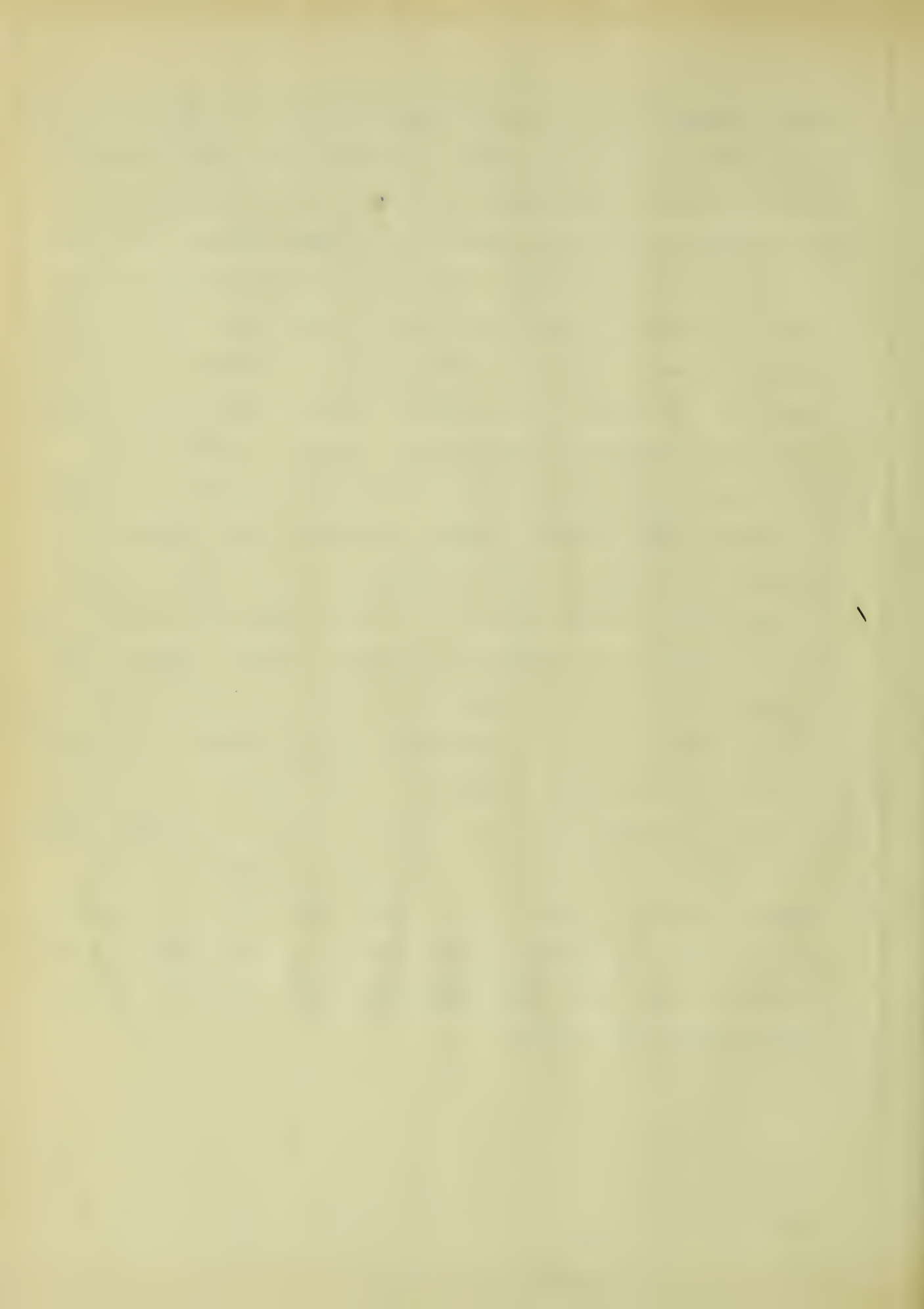
The test pieces used were 30 inches long and were of three different sizes; 1 1/4 in., 1 5/8 in. and 2 in. in diameter. Tests were made on both the cold rolled and turned shafting, and the tests were run in duplicate. The machine used for testing the shafts was a 230,000 inch pound, Olsen torsion machine in the laboratory of Applied Mechanics of the University of Illinois, having a grip capacity of a shaft three inches in diameter, and is shown plainly in Fig. I, below. At first center holes were drilled in the shafts and the pieces were placed on centers in the heads of the machine but it was found that just as good results could be obtained by not using the centers, but simply adjusting the pieces by means of the jaws. This was done by adjusting the chuck screws until the opposite jaws were equally distant from the center when they gripped the specimen. After the pieces were placed in the machine, the apparatus for finding the elastic limit was adjusted on the shaft. This consisted of a scale attached to an arm at one end of the test piece and a pointer attached to the other end and moving over the scale as shown in Fig. I, at A. A zero load was placed on the machine and then the pointer was set at a starting point on the scale generally at the 1 inch mark. Then using the low speed, the pointer was allowed to advance over the scale in equal in-

crements and the load was read after each increment. In this way the amount of torsion and the twisting moment was found, and from them a curve showing the relation between the two was plotted. After the data for finding the elastic limit had been taken, the scale and pointer were removed and the fast speed put on and the piece allowed to break. By keeping the beam balanced the maximum twisting moment and breaking load were noted, and by counting the number of revolutions of the moving head the number of twists were taken.

The sizes and forms of the keyways used in the test are grouped together and the dimensions of the keyways are given below, the first being the width and the second the depth of the keyway. The stress at the elastic limit of each shaft is also given below the drawing so that comparison may be made between them. It may be noticed that the width of the key as given in Kent is slightly less than the depth to allow for finishing on the sides, so that the width of the standard keyway would be less than twice the depth. This was not taken in cutting the keyways as the cutters were only made in sixteenth sizes and by not allowing for the finish on the key the keyways could be cut much quicker. Thus instead of having the keyways $7/32$ in. wide they were $1/4$ in. wide. As the width of the keyway has very little effect on the strength of the shaft, as shown by these tests, the difference in results is very slight.

The data taken during the test were recorded in a log book which can be found in the office of the Laboratory of Applied Mechanics. A sample of the notes taken in one test is

shown on page 6 and the sample calculations for finding the stress per square inch is given below. From the data taken a curve is plotted using the deflection of the pointer as abscissae and the stresses in the solid shaft of a diameter equal to that of the test piece as ordinates. As there was no noticeable yield point in any of the pieces the elastic limit had to be found by graphical means. The point found was not the "true elastic limit" but was called the "apparent elastic limit" by Professor J. B. Johnson who first proposed it. Wishing to get a point which could be adopted as standard since the methods of finding the elastic limit varied, greatly, he drew a line tangent to the stress-deformation curve and having $1\frac{1}{2}$ times as great a slope with the vertical as the initial part of the curve. The point of tangency he called the "apparent elastic limit". Thus on page 7, AB is the elastic curve and AC the straight line where the deflection is proportional to the stress. Then the line AD is drawn having a slope with the vertical $1\frac{1}{2}$ times as great as AC, and this line is moved parallel to itself until it is tangent to the curve and the point of tangency is the "apparent elastic limit". It has been found that the "apparent elastic limit" is slightly greater than the "true elastic limit" but as the tests made were comparative tests this does not seriously affect the results.



SAMPLE NOTES.

Shaft No. 80.

7/16 in. Sq. keyway.

$$d = 2.001".$$

Indicator ins.	Scale in.-lbs.	Computed Stress lbs/sq. in.
1.0	6000	3830
1.1	12425	7900
1.2	18572	11800
1.3	24700	15700
1.4	31650	20200
1.5	37650	24000
1.6	42800	27200
1.7	48150	30750
1.8	52600	33500
1.9	55300	35150
2.0	58625	
Max.	100000	63700
Break.	90000	57300

SAMPLE CALCULATIONS.

$$P_p = \frac{S J}{r}, \quad \frac{J}{r} = \frac{d^3}{16} = 1.564,$$

$$S = \frac{6000}{1.564} = 3830 \text{ lbs. per sq. in.}$$

45000

40000

35000

30000

25000

20000

15000

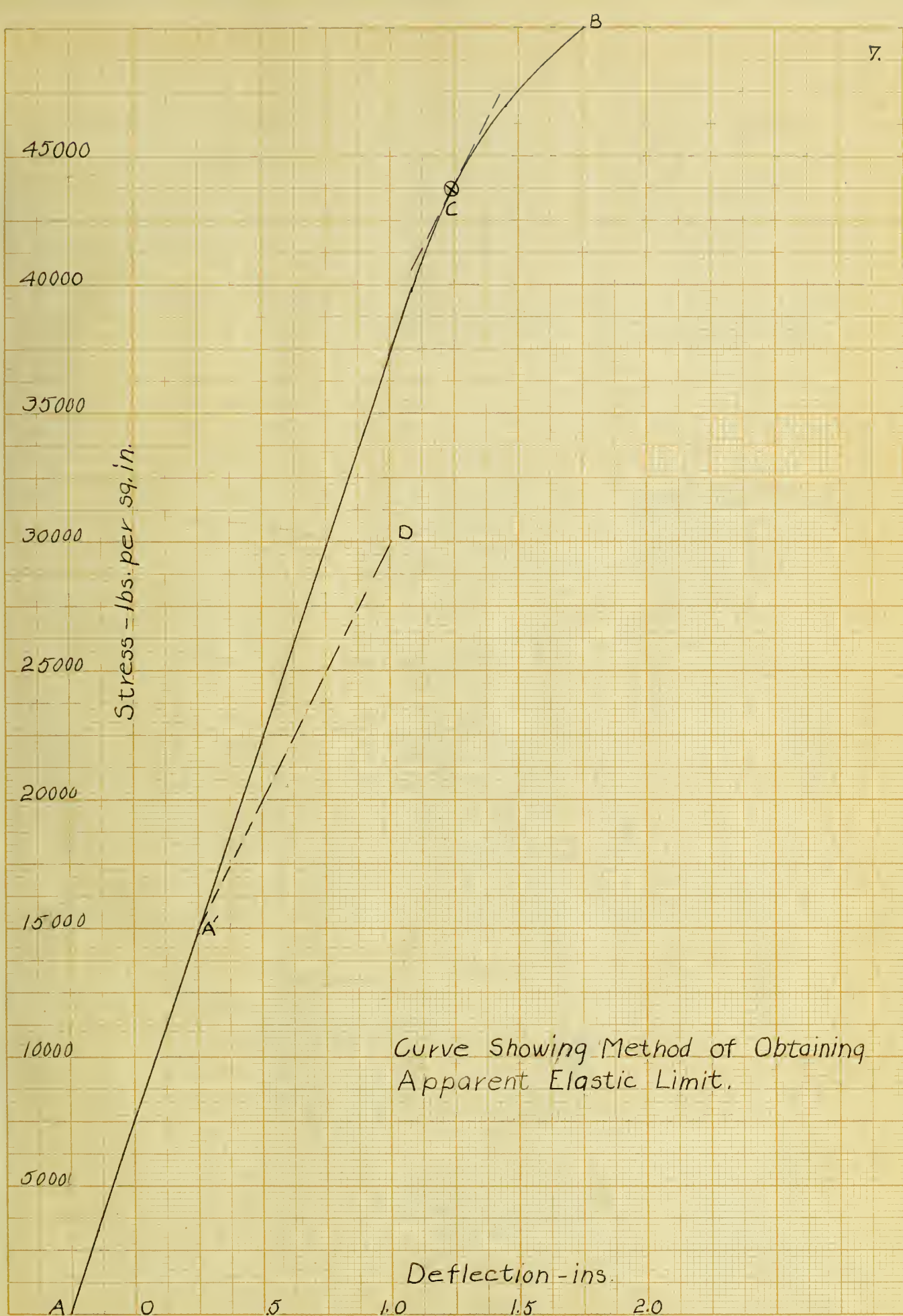
10000

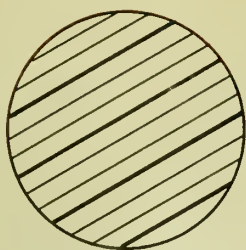
5000

Stress - lbs. per sq. in.

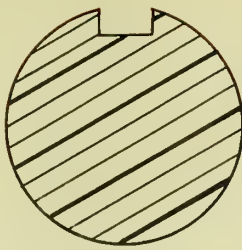
Deflection - ins.

A 0 .5 1.0 1.5 2.0

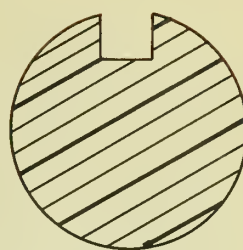




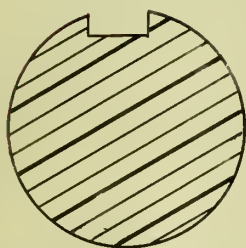
1 1/4" Plain.
E.L 43400 # per sq in



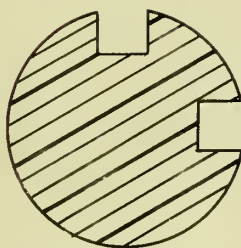
1/4"x1/8" Std.
Keyway
Loss of Strength
4.5 %



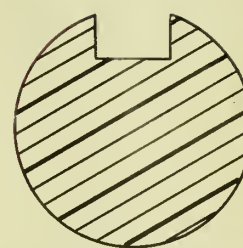
1/4"x1/4"
Keyway
Loss of Strength
12.0 %



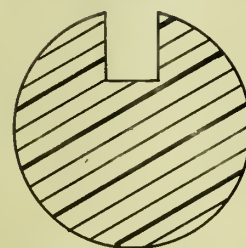
3/8"x1/8" Kv.
Loss of Strength
7.0 %



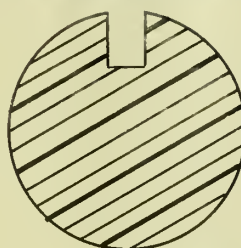
2-1/4" sq. Kvs.
Loss of Strength
35.0 %



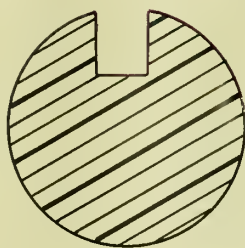
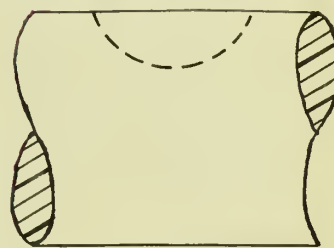
3/8"x1/4" Ky.
Loss of Strength
14.0 %



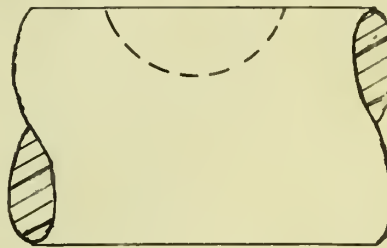
1/4"x3/8" Keyway
Loss of Strength
35.0 %



Woodruff No.10.
Loss of Strength
1.6 %



Woodruff No. 15.
Loss of Strength
4.0 %

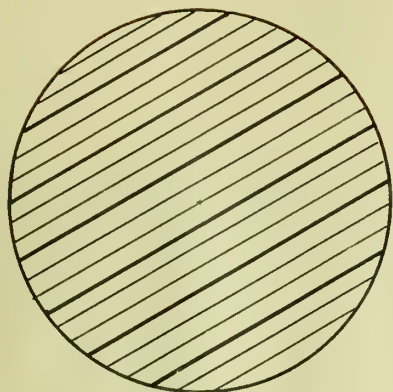


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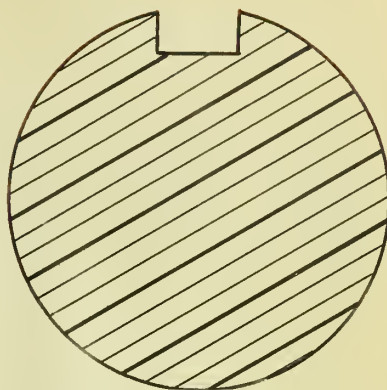
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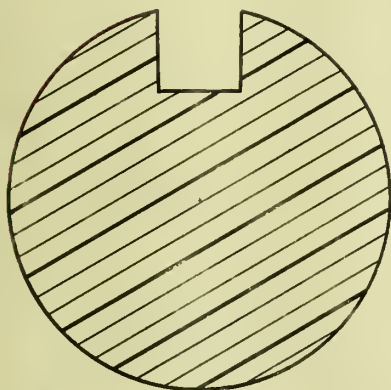
2" Plain.

E.L. 35150 # per sq. in.



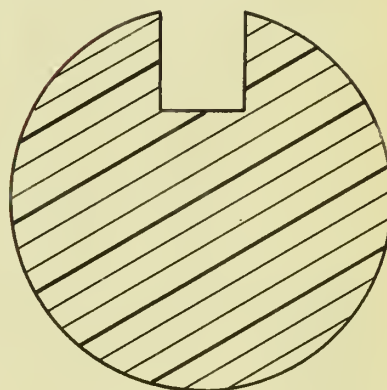
7/16"x7/32" Std. Ky

E.L. 34500 # per sq in.
Loss of Strength 2 %



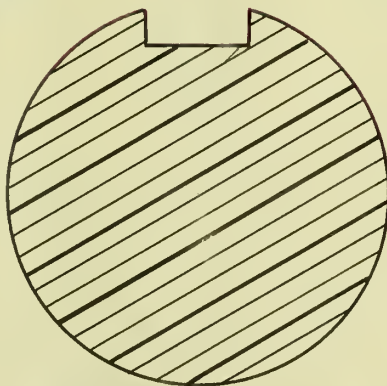
7/16"x7/16" Ky.

E.L. 33600 # per sq. in.
Loss of Strength 4.3 %



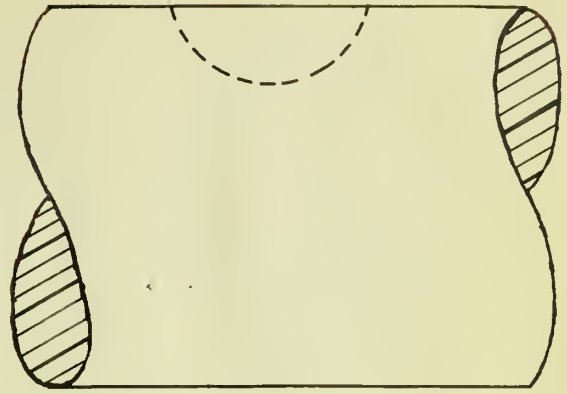
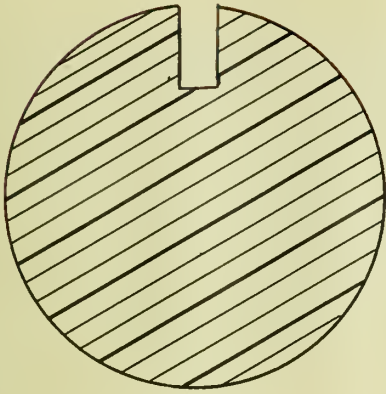
7/16"x9/16" Ky.

E.L. 25000 # per sq. in.
Loss of Strength 29 %



9/16"x7/32" Ky.

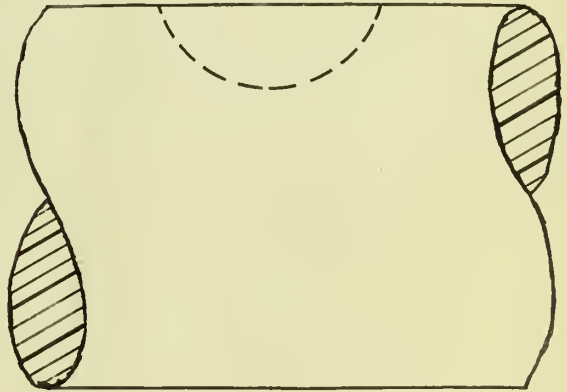
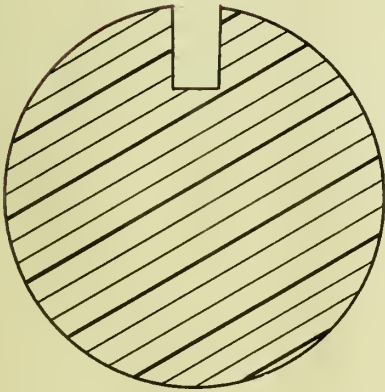
E.L. 33200 # per sq. in.
Loss of Strength 5.6 %



Woodruff No. 16.

E.L. 34000# per sq. in.

Loss of Strength 32%.

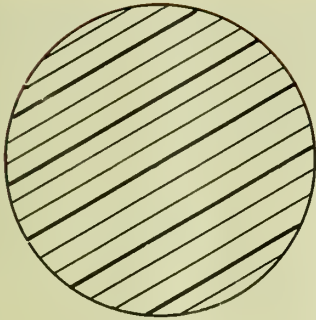


Woodruff No. 21.

E.L. 32500# per sq. in.

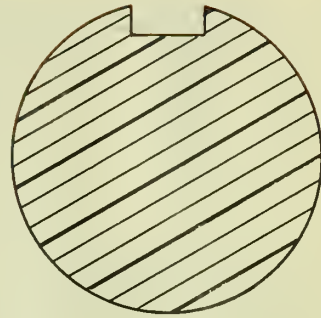
Loss of Strength 7%.





1 5/8" Plain.

E.L. 41300# per sq. in.

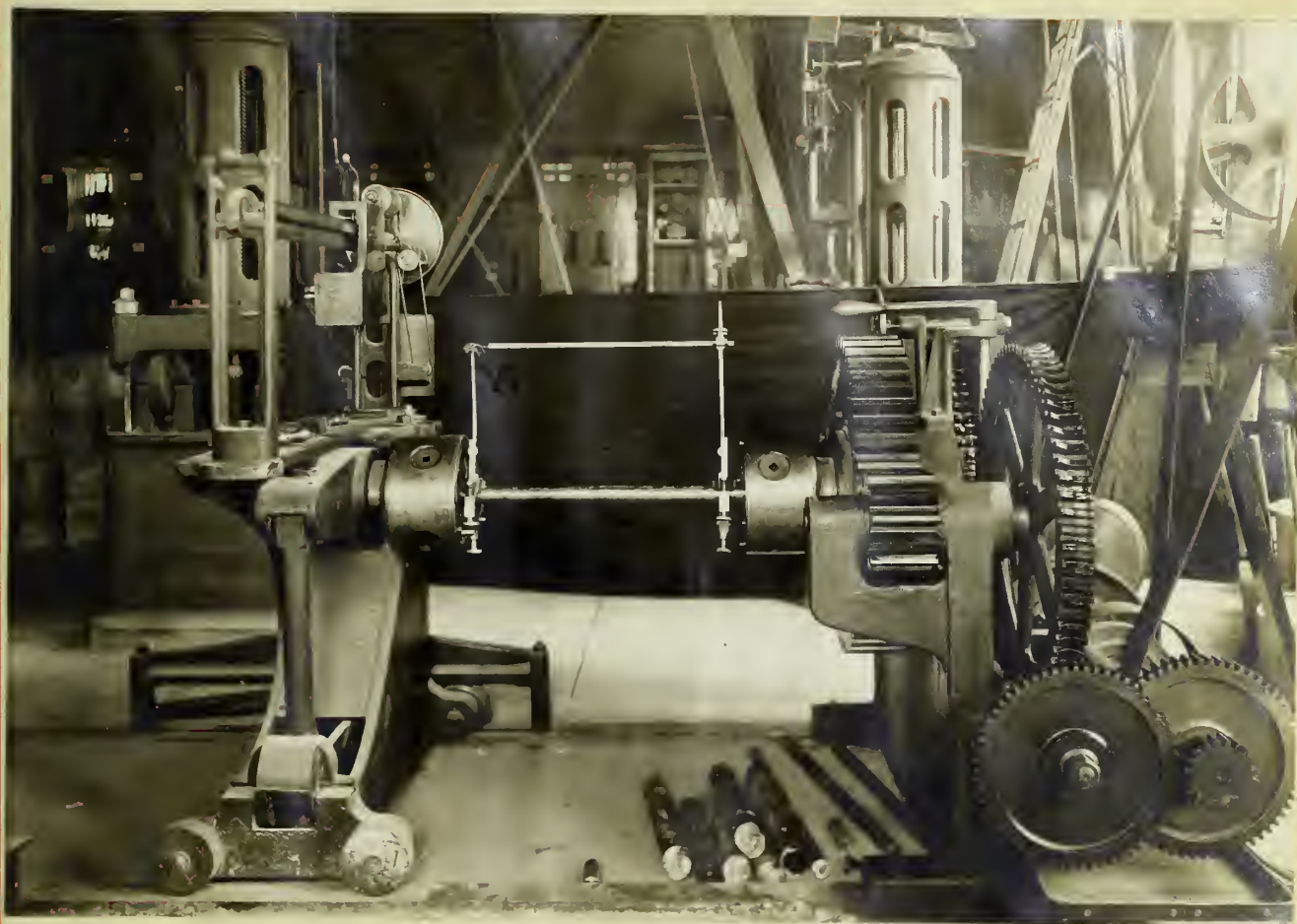


1 1/32"x1 1/64" Std. Ky.

E.L. 39800# per sq. in.

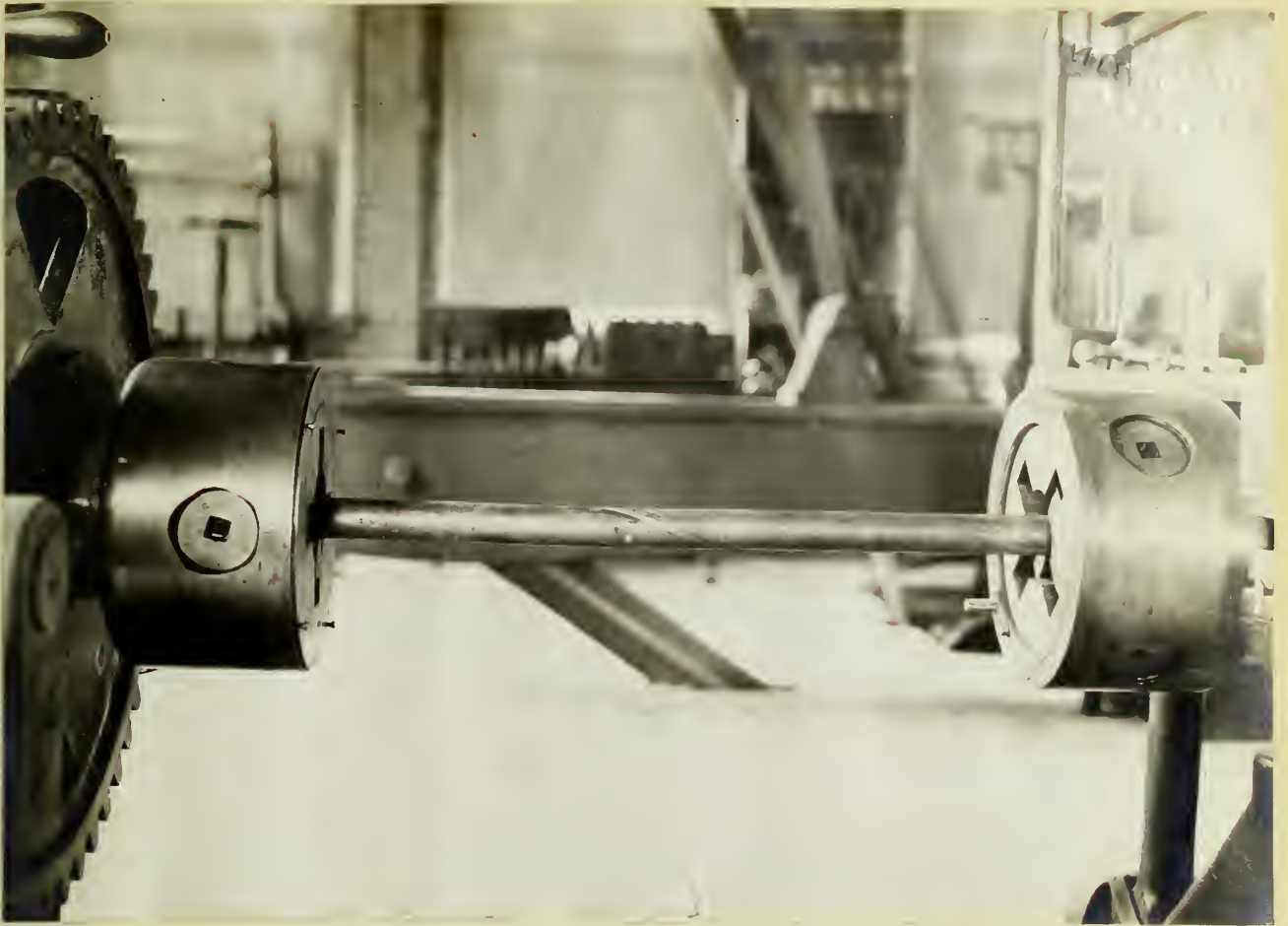
Loss of Strength 3.8%.

Figure 1.



Shaft ready for Testing.

Figure 2.



Shaft after one revolution.

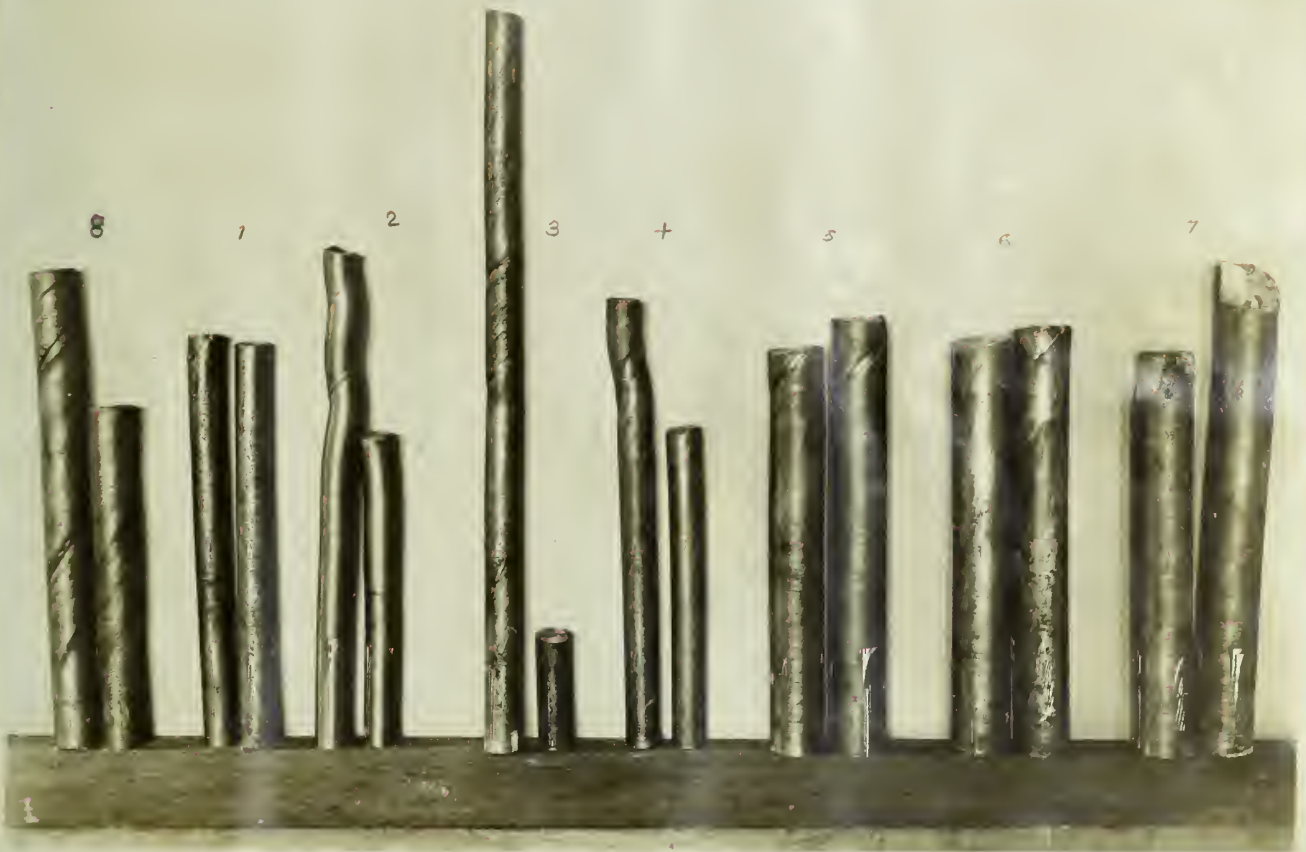


Figure 3.



Shaft after rupture.

Figure 4.



Broken shafts.

TABLE NO.1.

1 1/4" Cold Rolled Shafts.

Size of Keyway	Solid	$\frac{1}{4} \times \frac{1}{8}$	$\frac{3}{8} \times \frac{1}{8}$	NO. 10. Woodruff.	NO. 15.	2-1/4" Sq.
Elastic Limit lbs. per sq. in.	43400	41500	40400	42700	41700	28500
Loss of Strength percent.		4.5	7.0	1.6	4.0	35.0
Maximum Comput- ed Stress. lbs. per sq. in.	71100	71000	70000	65800	67600	65200
Twists.	4 3/4	4 1/2	3 3/4	3/4	7/8	2 1/8
Place of break	Grip.	Grip.	Grip.	Keyway.	Keyway.	Keyway.

TABLE NO. 2.

1 1/4" Cold Rolled Shaft.

Size of Keyway	Solid	$\frac{1}{4} \times \frac{1}{4}$	$\frac{3}{8} \times \frac{1}{4}$	$\frac{1}{4} \times \frac{3}{8}$
Elastic Limit lbs. per sq. in.	41500	36500	35800	27800
Loss of Strength percent.		12	14	33
Maximum Comput- ed stress. lbs. per sq. in.	70000	71000	78000	63000
Twists.	4 3/8	4 7/8	2 1/2	2 1/8
Place of break	Grip.	Keyway.	Keyway.	Keyway.

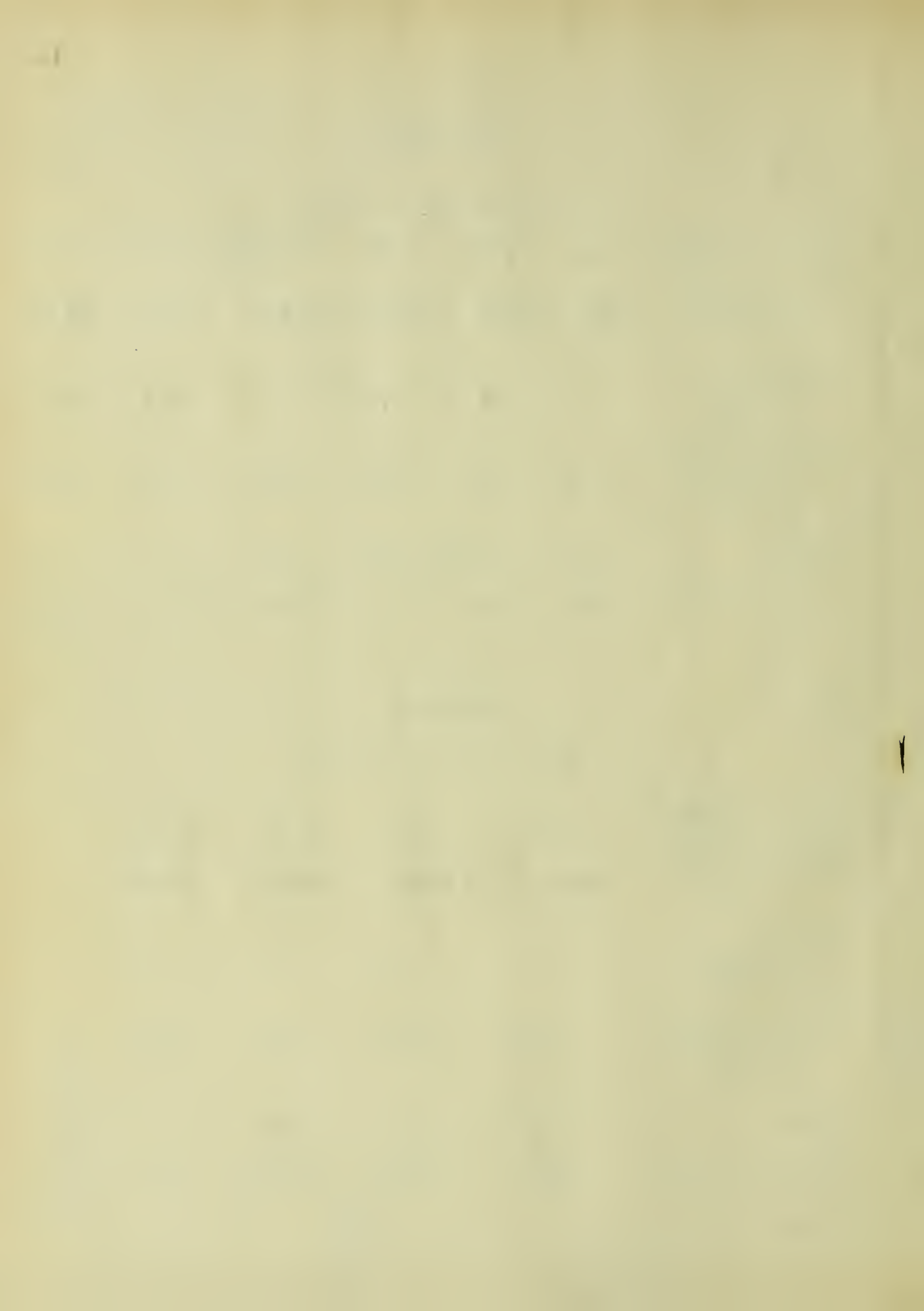


TABLE NO. 3.

2" Cold Rolled.

Size of Keyway	Solid	7"x7" 16 32	7"x7" 16 16	7"x9" 16 16	9"x7" 16 32	No. 16 Woodruff.	NO. 21.
Elastic Limit lbs. per sq. in.	35150	34500	33650	25000	33200	34000	32000
Loss of Strength percent.		2.0	4.3	29.0	5.6	3.2	7.0
Maximum Comput- ed Stress. lbs. per sq. in.	66000	65000	64600	60000	66500	67000	64000
Twists.	5	3 1/2	2 1/4	2	4	1 1/2	1 7/8
Place of break.	G	K.W.	K.W.	K.W.	G		K.W.

TABLE NO. 4.

1 1/4" Turned.

Size of Keyway	Solid	1/4" sq.	1/4"x3/8"	NO. 10. Woodruff.	NO. 15.
Elastic Limit lbs. per sq. in.	22500	21000	16800	21200	20500
Loss of Strength percent.		7.0	25.0	6.0	8.0
Maximum Comput- ed Stress. lbs. per sq. in.	65200	66400	65700	61000	62100
Twists.	4 5/8	6 1/8	6	4	4 1/8
Place of break.	Grip.	Keyway.	Keyway.	Keyway.	Keyway.

TABLE NO. 5.

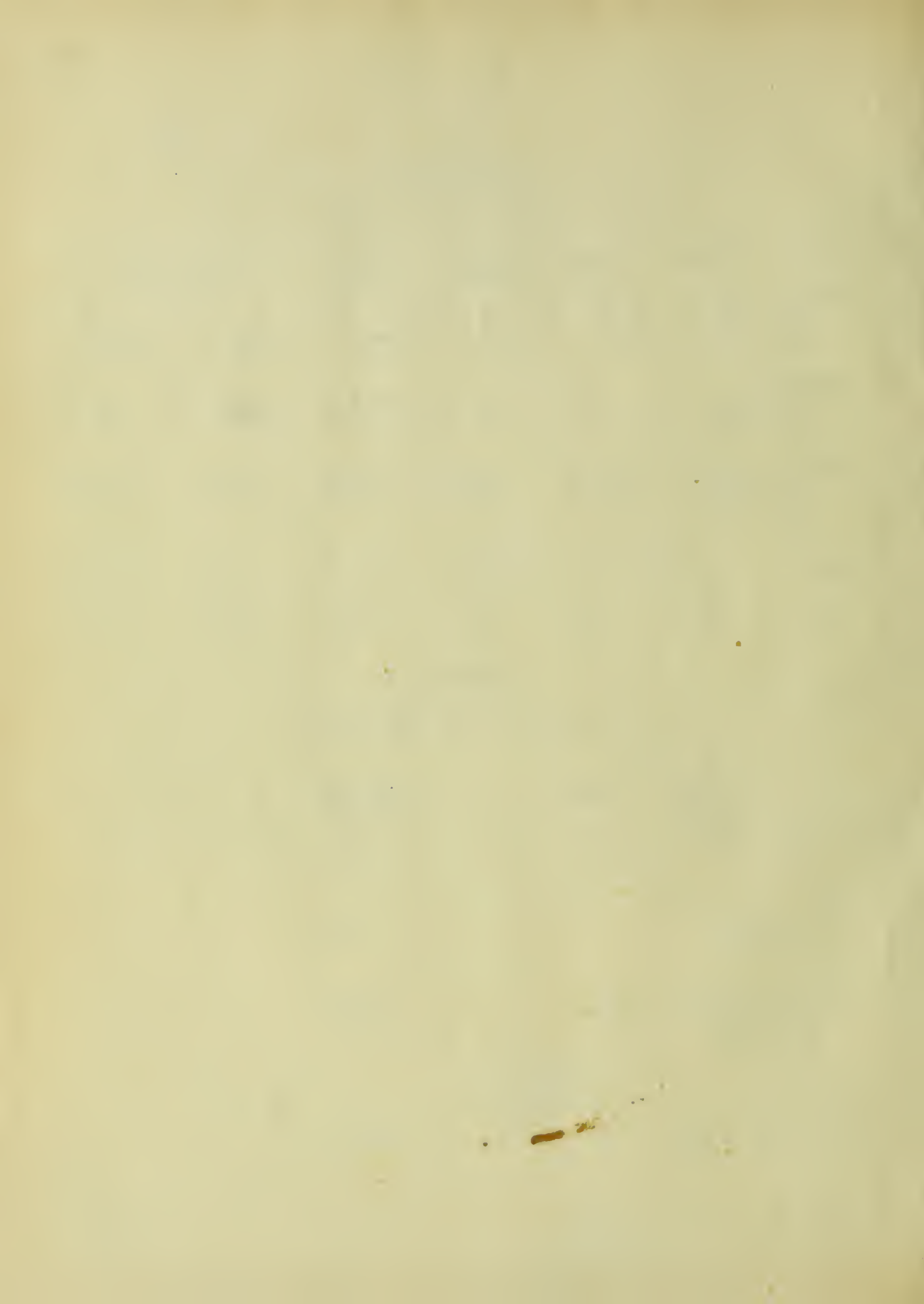
2" Turned Shafts.

Size of Keyway.	Solid	$\frac{7"x7"}{16 \ 32}$	$\frac{9"x7"}{16 \ 32}$	NO. 16. Woodruff.	NO. 21.
Elastic Limit lbs. per sq. in.	17500	16400	15500	16200	15800
Loss of Strength percent.		6.0	11.5	7.5	9.7
Maximum Comput- ed Stress. lbs. per sq. in.	64000	60000	60000	57200	54100
Twists.	4	3 $\frac{7}{8}$	3 $\frac{3}{8}$	2 $\frac{1}{4}$	2 $\frac{3}{8}$
Place of break.	G	K.W.	K.W.	K.W.	K.W.

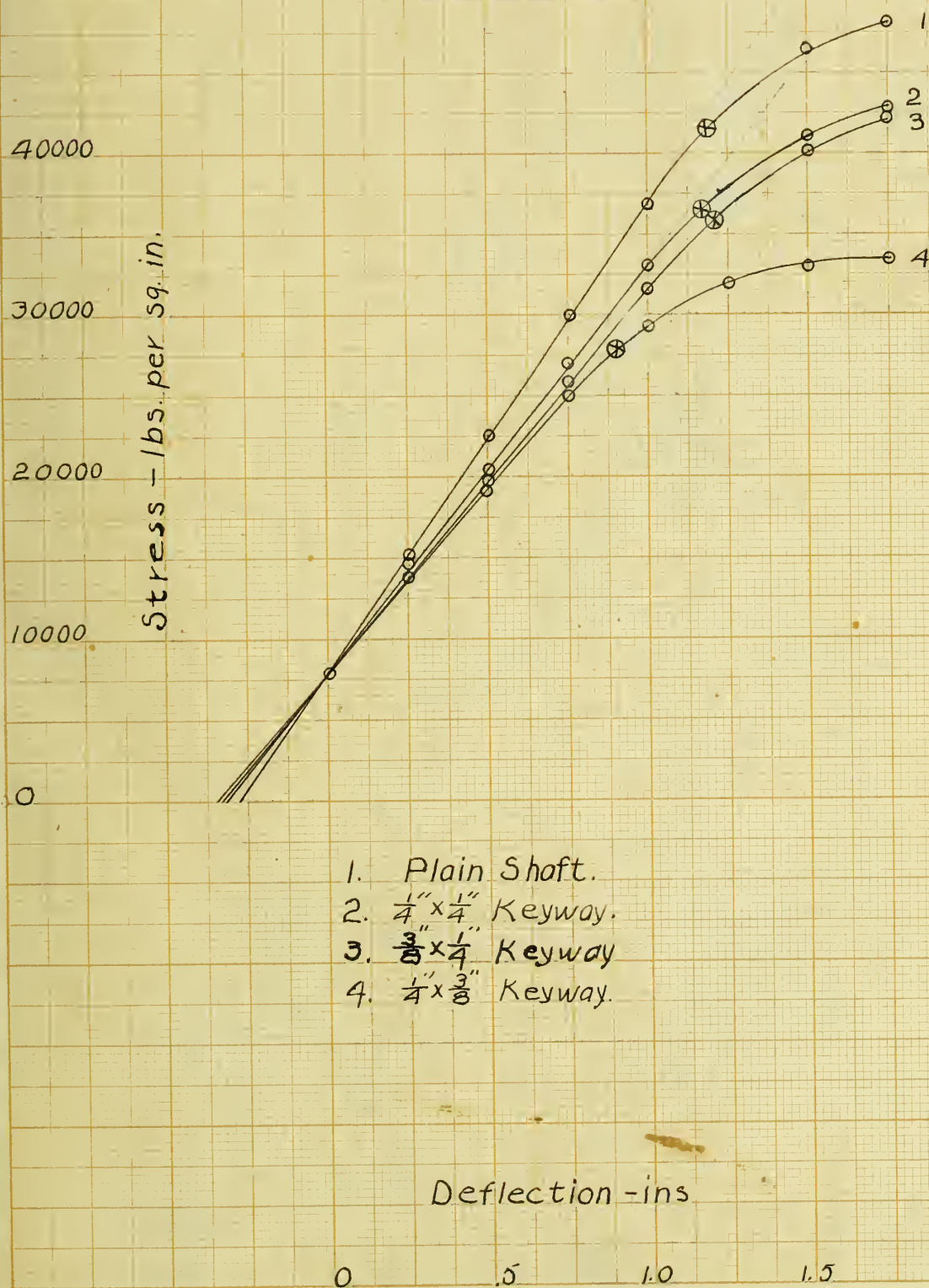
TABLE NO. 6.

1 $\frac{5}{8}$ " Cold Rolled Shafts.

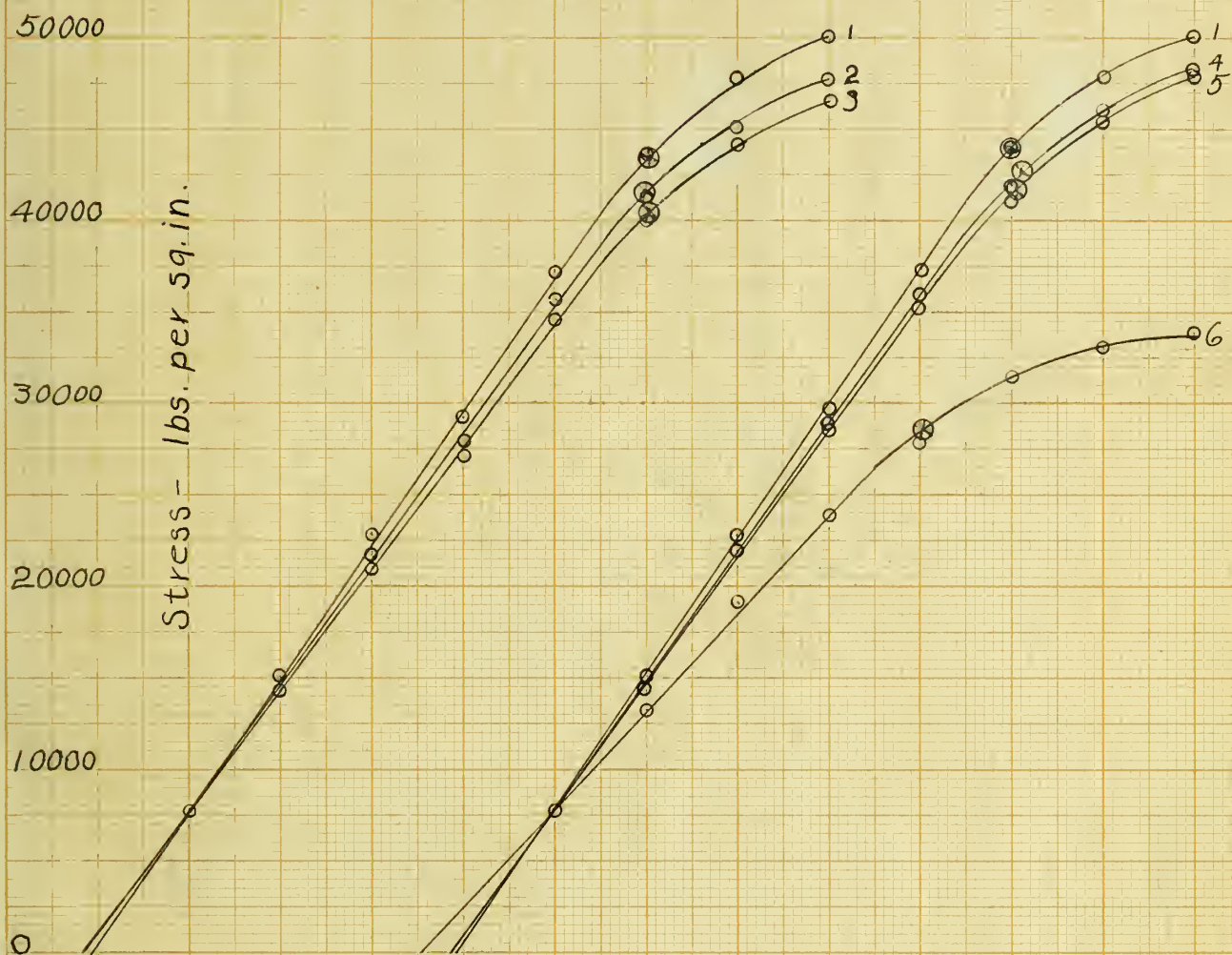
Size of Keyway.	Solid	$\frac{11"}{32}$ $\frac{11"}{64}$
Elastic Limit lbs. per sq. in.	41300	39800
Loss of Strength percent.		3.8
Maximum Comput- ed Stress. lbs. per sq. in.	65000	67000
Twists.	3 $\frac{5}{8}$	4
Place of break.	G	K.W.



$1\frac{1}{4}$ " Cold Rolled Shafts



$1\frac{1}{4}$ " Cold Rolled Shafts.



1. Plain Shaft.

2. $\frac{1}{4}$ " \times $\frac{1}{8}$ " Keyway.

3. $\frac{3}{8}$ " \times $\frac{1}{8}$ " Keyway.

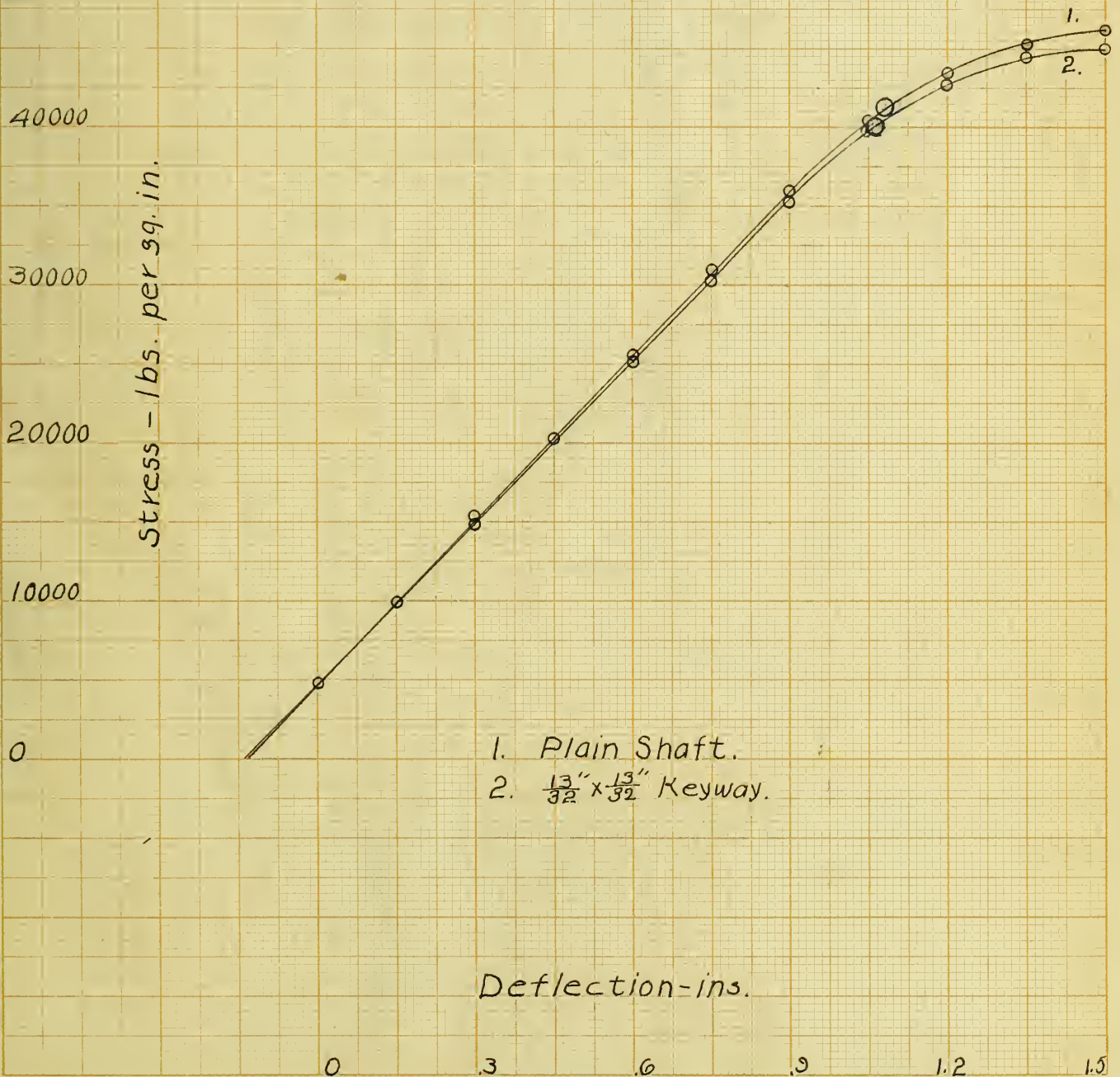
4. Woodruff #10.

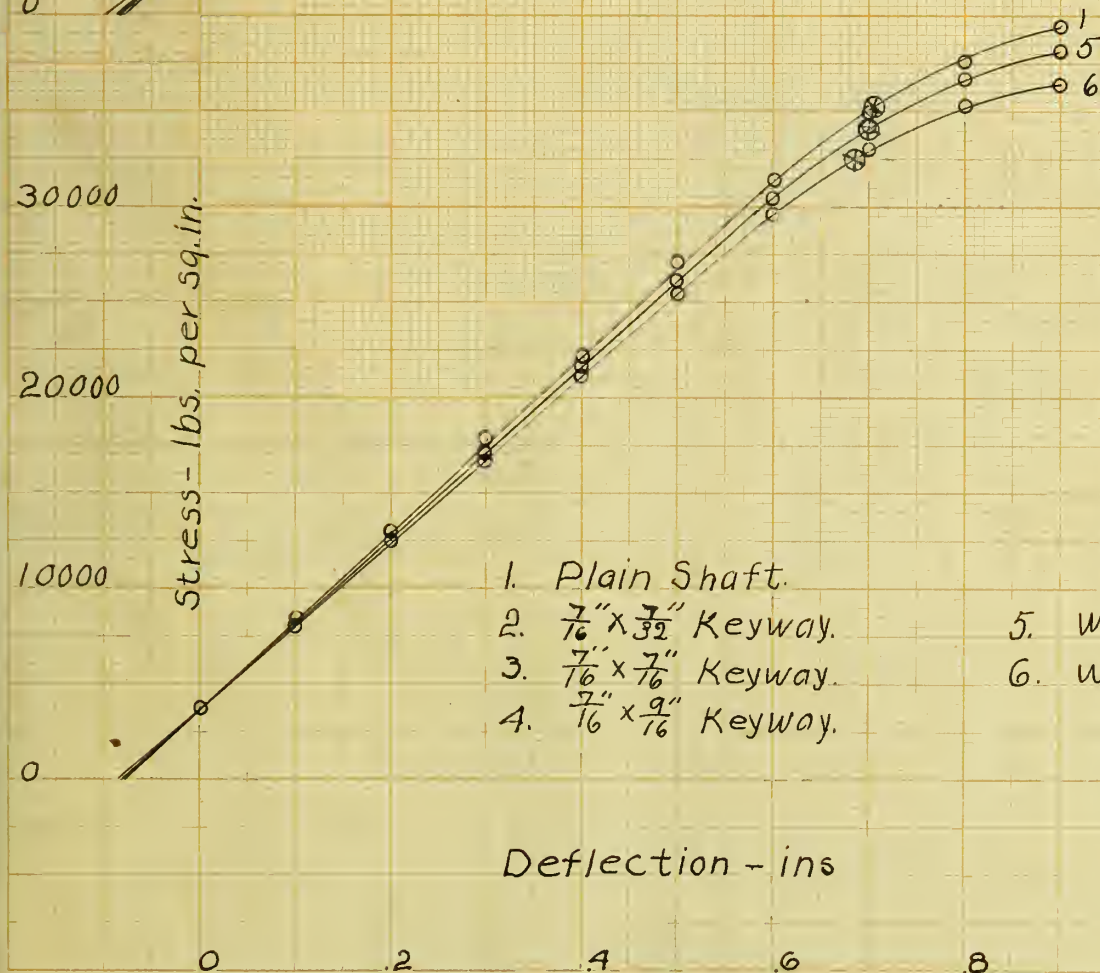
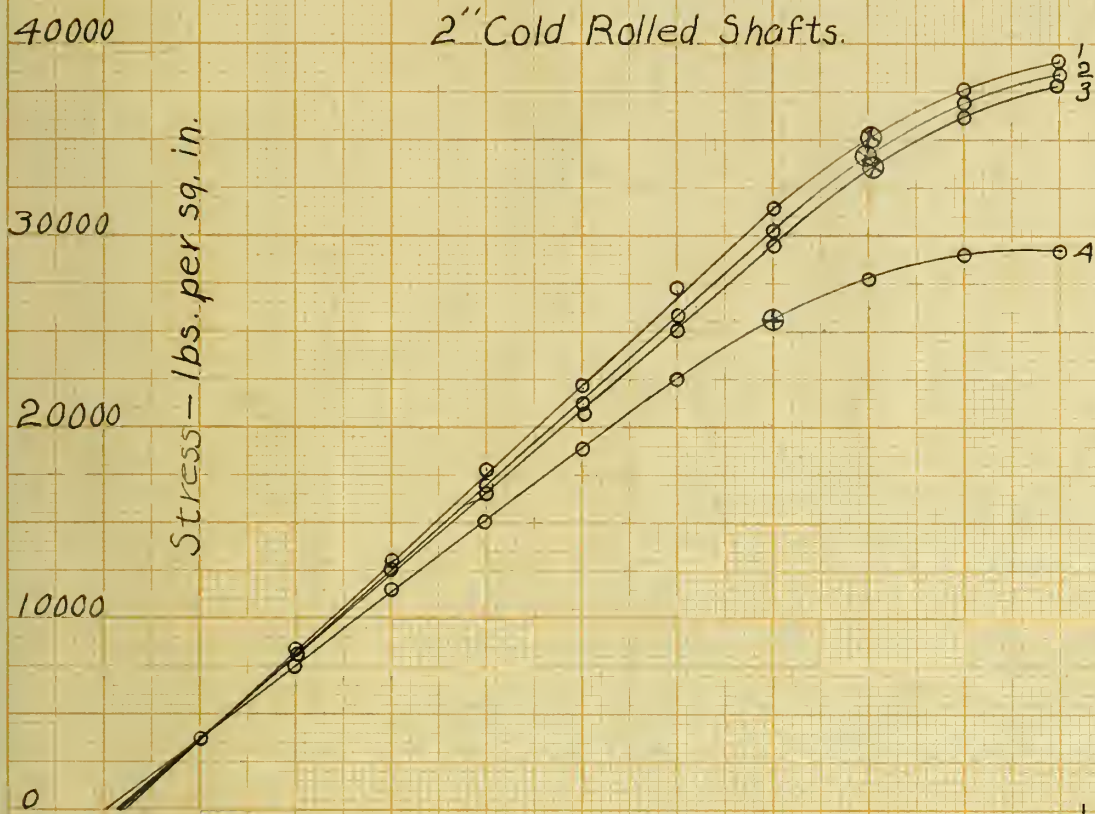
5. Woodruff #15.

6. 2 Keyways Rt. angle.

Deflection - ins.

0 0.5 1.0 1.5 1.0 1.5

$1\frac{5}{8}$ " Cold Rolled Shafts.

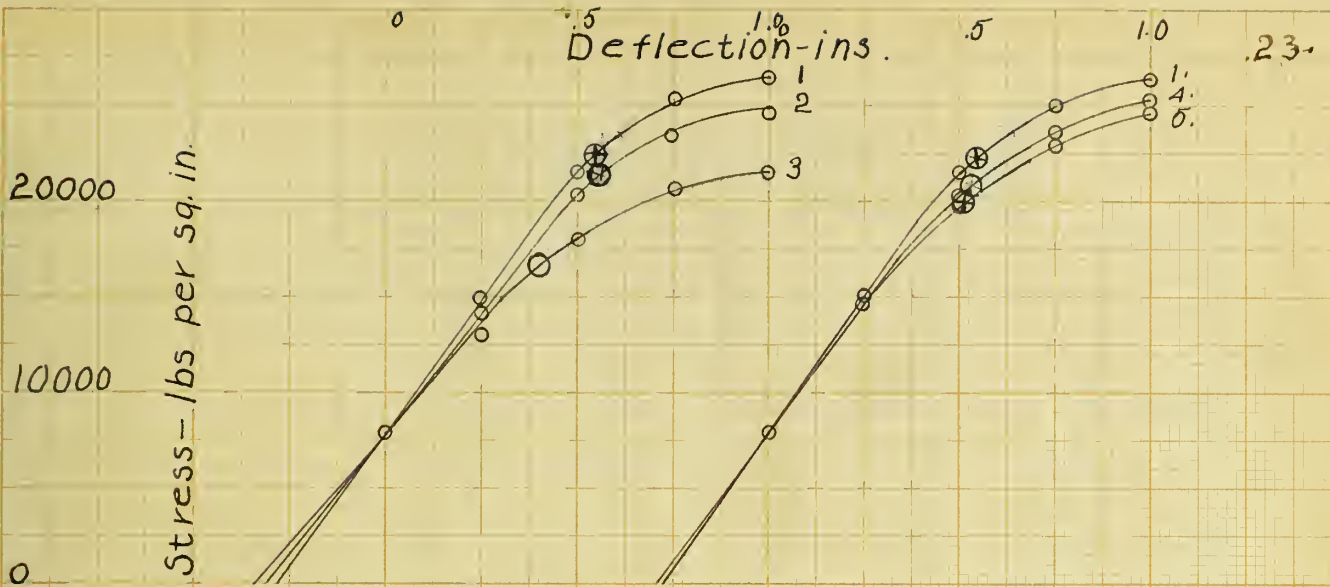


1. Plain Shaft.

2. $\frac{7}{16} \times \frac{3}{32}$ Keyway.3. $\frac{7}{16} \times \frac{7}{16}$ Keyway.4. $\frac{7}{16} \times \frac{9}{16}$ Keyway.

5. Woodruff #16.

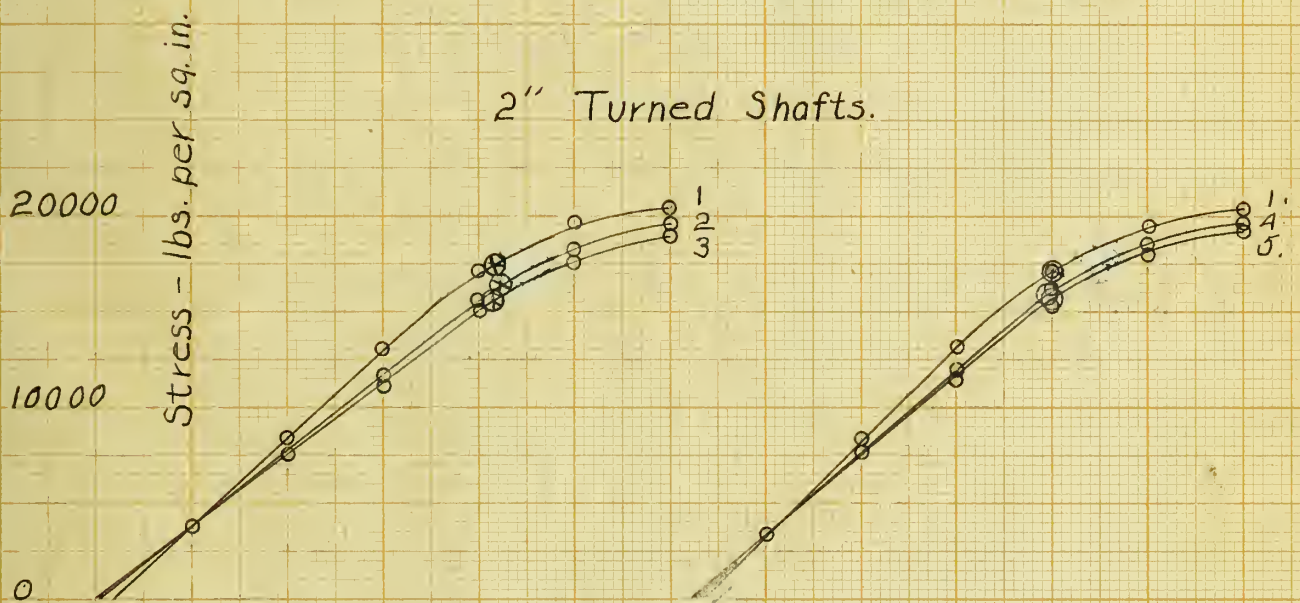
6. Woodruff #21.



1 1/4" Turned Shafts.

1. Plain Shaft.
2. 1/4" x 1/4" Keyway.
3. 1/4" x 3/8" Keyway.

4. Woodruff #10
5. Woodruff #15



2" Turned Shafts.

1. Plain Shaft
2. 7/16" x 7/32" Keyway.
3. 9/16" x 7/32" Keyway.

4. Woodruff #16.
5. Woodruff #21.

Deflection-ins. 0 2 4 0 2 4

GENERAL DISCUSSION.

In Fig. 2, the test piece is shown after it has been twisted around once and the keyway has closed slightly. The load on the shaft is very unsteady while the keyway is closing, running up almost to the maximum and then dropping off suddenly showing that the metal around the keyway gives away by jerks. In the Fig. the depression in the shaft shows plainly where the keyway was but it has closed up tightly. In the standard sized keyway the sides did not come together and generally the shaft broke at the grip. In the last photograph some of the characteristic specimens are shown after rupture. Shafts No. 1 and No. 6, are those having keyways for the Woodruff key and they broke off quickly after only about 1 turn. No. 3 and No. 5 are standard keyways, the latter breaking at the keyway which is unusual. The rest are all deep keyways except No. 7 which was a plain shaft and shows a break more like cast iron than steel.

One of the difficulties in the investigation was that the test pieces were not all of the same quality of steel and the comparison of results was thus more difficult. In some cases additional tests were necessary in order to check the work as is shown in tables NO. 1 and NO. 2 where there is a difference of 5000 pounds in the strength of the two steels used. It is seen from the tables that the maximum load carried is about the same whether the shaft has a keyway in it or not.

From an examination of the tables and curves the following conclusions may be drawn:

CONCLUSIONS.

1. The standard size keyway as given by Kent's formula in no case showed a weakening of the solid shaft by more than 8% of its strength at the elastic limit.

2. The wide keyway doesnot weaken the shaft much more than the one of square section.

3. For the larger sized shafts the depth of keyway may be made greater than the di^mensions given in Kent without seriously weakening the shaft.

4. The Woodruff keyway probably weakens the shaft less than any of the other forms tested where the stress is fairly steady. The shaft containing the Woodruff keyway breaks with about one-fourth the number of turns that one containing a standard square keyway will stand and shows that the Woodruff keyway probably has less shock resisting powers.

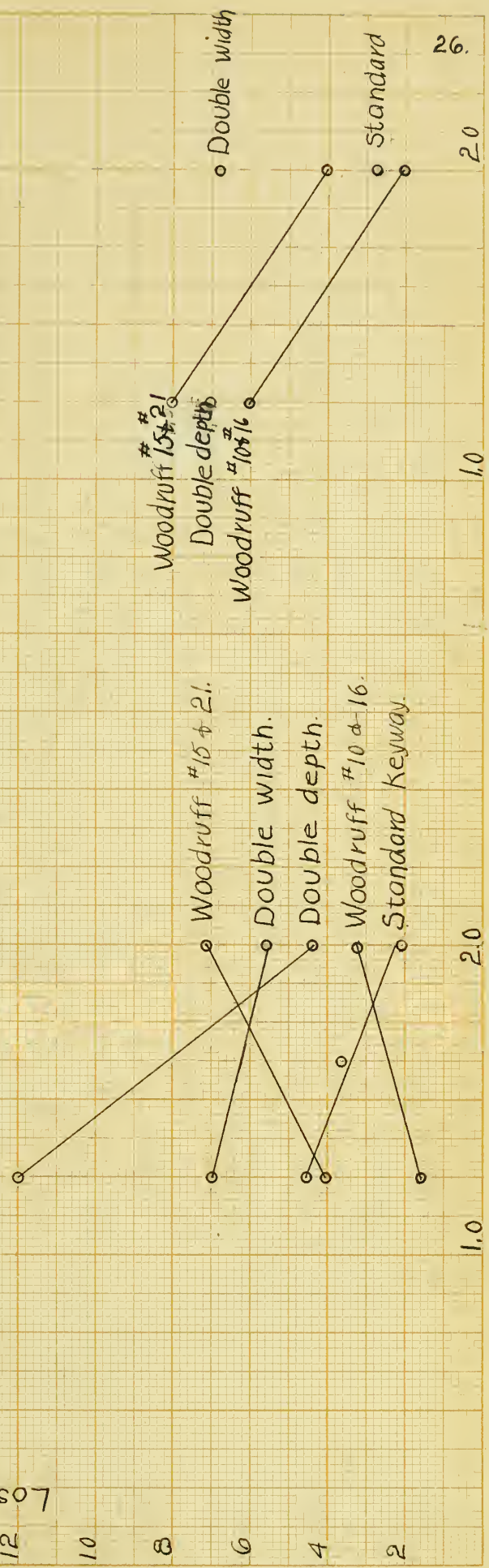
5. The effect of the keyway on the cold rolled shafting is not much different from that on the turned.

6. The stiffness of the shaft is decreased slightly by the keyways as may be seen from the cruves, the difference being much greater with the deeper keyways.

As all shafts are subjected to a bending stress it would probably be desirable in a more complete investigation to make a combined twisting and beiding test. The repeated load twisting test would also be useful as the loads in most cases are not continuous. This could be done by running the load almost up to the elastic limit and then taking it off and repeating this a large number of times.

Graphical Conclusions.

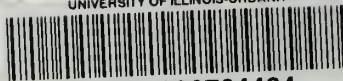
Loss of Strength - per cent.







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